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0618196.0

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3. Title of the invention: "An Improved Mist Generating Apparatus and Method"

4. Name of your agent *(if you have one)*: Murgitroyd & Company

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An Improved Mist Generating Apparatus and Method

The present invention relates to the field of mist generating apparatus. More specifically, the invention is directed to an improved apparatus and method for generating liquid droplet mists.

Mist generating apparatus are known and are used in a number of fields. For example, such apparatus are used in both fire suppression and cooling applications, where the liquid droplet mists generated are more effective than a conventional fluid stream. Examples of such mist generating apparatus can be found in WO2005/082545 and WO2005/082546 to the same applicant.

A problem with conventional mist generating apparatus is that not all of the working fluid being used is atomised as it passes through the apparatus. Although the majority of the working fluid is atomised upon entry into the mixing chamber of the apparatus, some fluid is pulled into the chamber but

is not atomised. The non-atomised fluid can stick to the wall of the mixing chamber and flow downstream along the wall to the outlet nozzle, where it can fall into the atomised fluid stream. This can cause the creation of droplets which are of non-uniform size. These droplets can then coalesce with other droplets to create still larger droplets, thus increasing the problem and creating a mist of non-uniform droplets.

In cooling applications in particular, the uniformity of the size of the droplets in the mist is important. In turbine cooling applications, for example, droplets which are over 10μm in diameter can cause significant damage to the turbine blades. It is therefore important to ensure control and uniformity of droplet size. Optimally sized droplets will evaporate, thus absorbing heat energy and increasing the air density in the turbine. This ensures that the efficiency of the turbine is improved. Existing turbine cooling systems employ large droplet eliminators to remove large droplets and thus prevent damage to the turbine. However, such eliminators add to the complexity and manufacturing cost of the apparatus.

It is an aim of the present invention to obviate or mitigate one or more of the aforementioned disadvantages.

According to a first aspect of the present invention there is provided an apparatus for generating a mist, comprising:

a generally cylindrical body; and

an elongate member co-axially located within the body such that a first transport fluid passage and a nozzle are defined between the body and the elongate member, the first transport fluid passage having a convergent-divergent internal geometry and being in fluid communication with the nozzle;

wherein the elongate member includes a working fluid passage and one or more communicating bores extending radially outwardly from the working fluid passage, the bores allowing fluid communication between the working fluid passage and the first transport fluid passage; and

wherein the one or more communicating bores are substantially perpendicular to the first transport fluid passage.

Preferably, the communicating bore has an inlet connected to the working fluid passage and an outlet connected to the working fluid passage, the outlet having a greater cross-sectional area than the inlet.

The body has an internal wall having an upstream convergent portion and a downstream divergent portion, the convergent and divergent portions at least in part forming the convergent-divergent internal geometry of the first working fluid passage. A first end of the elongate member has a

cone-shaped projection, wherein the nozzle is defined between the divergent portion of the internal wall and the cone-shaped projection. The one or more communicating bores are adjacent the first end of the elongate member.

Preferably, the cone-shaped projection has a ramped portion extending upwardly from the surface thereof.

In a first preferred embodiment, the elongate member further includes a second transport fluid passage having an outlet adjacent the end of the cone-shaped projection. Preferably, the first and second transport fluid passages are substantially parallel. The second transport fluid passage preferably includes an expansion chamber adjacent its outlet.

In a second preferred embodiment, the bores allowing communication between the working fluid passage and the first transport fluid passage are first bores, and the body further includes a second working fluid passage and one or more second communicating bores allowing fluid communication between the second working fluid passage and the first transport fluid passage. Preferably, the second working fluid passage circumscribes the first working fluid passage and the first transport fluid passage. Preferably, the second bores are substantially perpendicular to the first transport fluid passage. Most preferably, the first and second bores are co-axial.

In a third preferred embodiment, the elongate member further includes:

a second transport fluid passage circumscribing the working fluid passage;

one or more first communicating bores extending radially outwardly from the working fluid passage, the first bores allowing fluid communication between the working fluid passage and the second transport fluid passage; and

one or more second communicating bores extending radially outwardly from the second transport fluid passage, the second bores allowing fluid communication between the second transport fluid passage and the first transport fluid passage;

wherein the first and second communicating bores are substantially perpendicular to the second and first transport fluid passages, respectively.

Preferably, the elongate member further includes a third transport fluid passage adapted to supply transport fluid into the second transport fluid passage adjacent the first and second communicating bores.

Alternatively, the first transport fluid passage communicates with the nozzle via an outlet and a second transport fluid passage in fluid communication with the outlet, wherein the second transport fluid passage has a convergent-divergent internal geometry and is substantially perpendicular to the first transport fluid passage.

As a further alternative, the apparatus further comprises a mixing chamber located between the first transport fluid passage and the nozzle, and a second transport fluid passage in communication with the mixing chamber and the first transport fluid passage, wherein the second transport fluid passage is adapted to supply transport fluid to the mixing chamber in a direction of flow substantially opposed to a direction of flow of transport fluid from the first transport fluid passage.

According to a second aspect of the invention, there is provided a method of generating a mist, the method comprising the steps of:

supplying a working fluid through a working fluid passage;

supplying a first transport fluid through a first transport fluid passage;

forcing the working fluid from the working fluid passage into the first transport fluid passage via one or more communicating bores extending radially outwardly from the working fluid passage;

accelerating the first transport fluid upstream of the communicating bores so as to provide a high velocity transport fluid flow; and

applying the high velocity transport fluid flow to the working fluid exiting the communicating bores, thereby imparting a shear force on the working fluid and atomising the working fluid to produce a dispersed droplet flow regime;

wherein the high velocity transport fluid flow is applied substantially perpendicular to the working fluid flow exiting the bores.

Preferably, the method further includes the steps of:

forcing the atomised working fluid from the first transport fluid passage into a second transport fluid passage via one or more second communicating bores extending radially outwardly from the first transport fluid passage;

supplying a second transport fluid through the second transport fluid passage;

accelerating the second transport fluid upstream of the second communicating bores so as to provide a second high velocity transport fluid flow; and

applying the second high velocity transport fluid flow to the atomised working fluid exiting the second communicating bores, thereby imparting a second shear force on the atomised working fluid and further atomising the working fluid;

wherein the second high velocity transport fluid flow is applied substantially perpendicular to the atomised working fluid flow exiting the second bores.

Preferred embodiments of the present invention will be described, by way of example only, with reference to the accompanying drawings, in which:

Figures 1(a)-1(e) show detail section views through a first embodiment of a mist generating apparatus;

Figure 2 shows a detail section view through a second embodiment of a mist generating apparatus;

Figure 3 shows a section view through a third embodiment of a mist generating apparatus;

Figures 4(a)-4(c) show detail section views through a fourth embodiment of a mist generating apparatus;

Figure 5 shows a detail section view through a fifth embodiment of a mist generating apparatus;

Figure 6 shows a detail section view through a sixth embodiment of a mist generating apparatus; and

Figure 7 shows a detail section view through a seventh embodiment of a mist generating apparatus.

Figure 1(a) shows a first embodiment of mist generating apparatus according to the present invention. The apparatus, generally designated 10, comprises a generally cylindrical body 12 and an elongate member 14 projecting co-axially within the body 12. The member 14 and body 12 are so arranged that a first transport fluid passage 16 and a nozzle 32 are defined between the two. The body 12 has an internal wall 18 which includes a convergent portion 20 upstream of a divergent portion 22. The elongate member 14 has an external wall 24 which is substantially straight and parallel to the longitudinal axis L shared by the body and elongate member. As Figure 1(a) is only a detail view, it will be appreciated that the entire apparatus is not

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illustrated in this figure. As the body 12 is generally cylindrical, a further portion of the body 12, mirrored about the longitudinal axis L, is present below the elongate member 14, but is not shown in Figure 1(a) for reasons of clarity. Thus, passage 16 is an annular passage surrounding the elongate member 14. The elongate member 14 ends in a cone-shaped projection 15.

The elongate member 14 includes a passage 26 for the introduction of a working fluid. The passage will therefore be referred to as the working fluid passage 26. The passage 26 extends along the length of the elongate member 14 and is also co-axial with the body 12 and elongate member 14. The passage 26 is blind, in that it ends in a cavity 28 located in the outer cone portion 15 of the elongate member 14. Extending radially outwardly from the passage 26 in a direction substantially perpendicular to the transport fluid passage 16 are one or more communicating bores 30. These bores 30 allow fluid communication between the working fluid passage 26 and the transport fluid passage 16. The outer cone portion 15 of the elongate member 14 and the divergent portion 22 of the internal wall 18 define a mixing chamber 19 which opens out into a nozzle 32 through which fluid is sprayed.

The operation of the first embodiment will now be described. A working fluid, such as water for example, is introduced from a working fluid inlet (not shown) into the working fluid passage 26. The

working fluid flows along the passage 26 until reaching the cavity 28. Upon reaching the cavity 28, the working fluid is forced through the bores 30 into the transport fluid passage 16. A transport fluid, such as steam for example, is introduced from a transport fluid inlet (not shown) into the transport fluid passage 16. Due to the convergent-divergent section of the passage 16 formed by the convergent and divergent portions 20,22 of the body 18, the passage acts as a venturi section, accelerating the transport fluid as it passes through the convergent-divergent section into the mixing chamber 19. This acceleration of the transport fluid ensures that the transport fluid flows past the ends of the bores 30 at very high, possibly even supersonic, velocity.

With the transport fluid flowing at such high velocity and the working fluid exiting the bores 30 into the passage 16 in a direction substantially perpendicular to the transport fluid flow, the working fluid is subjected to very high shear forces by the transport fluid. Droplets are sheared from the working fluid flow as it exits the bores 30 producing a dispersed droplet flow regime. The atomised flow is then carried out through the mixing chamber 19 to the nozzle 32. In such a manner, the apparatus 10 creates a flow of substantially uniform sized droplets from the working fluid.

Figures 1(b)-1(e) show potential modifications to the nozzle 32 adjacent the outlet of the bores 30:

Figures 1(b)-1(d) show nozzles where the outlet of the bore 30 has a greater cross-sectional area than the inlet 29 communicating with the working fluid passage 26. In Figure 1(b) the bore 30 has a curved outward taper at the outlet 31b which provides the outlet 31b with a bowl-shaped profile when viewed in section. In Figure 1(c), a similar arrangement is shown, but here the expanded diameter of the outlet 31c is achieved by providing a stepped portion rather than a gradual outward taper. With the nozzle of Figure 1(d), the bore 30 gradually tapers outwards along the length thereof from inlet 29 to outlet 31d.

By providing bores 30 whose outlets 31b,31c,31d are of greater diameter than their respective inlets 29, an area of lower pressure is provided in the working fluid as it leaves the outlets 31b,31c,31d. This has the effect of presenting a greater surface area of working fluid to the transport fluid in the mixing chamber 19, thereby further increasing the shear effect of the transport fluid on the working fluid. Additionally, the expansion of the bores 30, particularly in the cases of the Figure 1(b) and 1(c) nozzles, will increase the turbulence of the working fluid flow as it exits the bores 30, limiting the potential for any of the working fluid flow to become trapped along the walls of the bores 30.

As explained above, one undesirable phenomenon in mist generating apparatus is that some of the

working fluid is not instantly atomised upon exit from the bores 30. In such instances, the non-atomised fluid can flow along the wall of the outer cone portion 15 of the nozzle 32 and then disrupt the size of the working fluid droplets which have already been atomised. This phenomenon can be avoided in the nozzle shown in Figure 1(e). With this nozzle, the wall of the outer cone portion 15 is provided with a ramped portion 34 which extends upwardly from the outer cone wall to a peak, also known as a surface separation point. Any non-atomised fluid flow along the outer cone 15 will flow up the ramped portion 34. Once the fluid flow arrives at the peak, it will be subjected to the shear forces of the transport fluid, will atomise, and then join the remainder of the droplets as they exit the nozzle 32.

Figure 2 shows a second embodiment of the apparatus, which also solves the same problem as the modified nozzle of Figure 1(e). In this instance, the elongate member 14 includes a working fluid passage 26 as before. However, instead of passing through the central axis of the elongate member 14 as in the previously described embodiments, in this embodiment the working fluid passage 26 is arranged so as to circumscribe a second transport fluid passage 40 located along the longitudinal axis of the elongate member 14. The purpose of the second transport fluid passage 40 is to ensure any non-atomised fluid which flows down the surface of the outer cone 15 is atomised when it reaches the outlet 42 of the

passage 40, which is adjacent the end of the outer cone 15. Thus, transport fluid flows through both the first transport fluid passage 16 and the second transport fluid passage 40. The second transport fluid passage 40 can include an expansion chamber 44 if desired, and is preferably substantially parallel to the first transport fluid passage 16.

A third embodiment of the apparatus is shown in Figure 3. This embodiment shares a number of features with the first embodiment described above. As a result, these features will not be described again in detail here, but have been assigned the same reference numbers, where appropriate. The first difference between the first and third embodiments is that the external wall 24′ of the elongate member 14 is of the same convergent-divergent geometry as the internal wall 18 of the body 12. Hence, the convergent and divergent portions 20,22 of the internal wall 18 are mirrored by identical portions of the external wall 24′ of the elongate member 14. As a result, both walls 18,24′ define a throat section 50 in the first transport fluid passage 16.

The second key difference between the third embodiment of the apparatus and the preceding embodiments is that as well as having a first working fluid passage 26 along the centre of the elongate member 14, a second working fluid passage 52 is also provided in the body 12, the second working fluid passage 52 circumscribing both the

first working fluid passage 26 and the transport fluid passage 16. This means that working fluid is supplied into the mixing chamber 19 from both first and second bores 30,54 which extend radially outwardly from their respective passages 26,52 and connect the first and second working fluid passages 26,52 with the transport fluid passage 16. As with the first working fluid passage 26, the second working fluid passage 52 is also blind, with a cavity 56 located at the end of the passage 52 remote from the working fluid inlet (not shown). The first and second bores 30,54 are preferably co-axial, as seen in section in Figure 3. This ensures that the working fluid enters the transport fluid passage 16 at the same point from both the first and second working fluid passages 26,52. The first and second bores 30,54 are substantially perpendicular to the transport fluid passage 16.

The third embodiment will operate in substantially the same manner as that described in respect of the first embodiment. Working fluid exiting the first and second bores 30,54 will be sheared by the transport fluid flowing through the transport fluid passage 16, thereby creating a mist of uniform sized droplets.

A fourth embodiment of the invention is illustrated in Figure 4(a). Again, the basic layout of the apparatus is the same as with the first embodiment, so like features have been again assigned the same reference numbers. The elongate member 14 has a

central working fluid passage 26 which ends in a cavity 28 remote from a working fluid inlet (not shown). A first transport fluid passage 16 is defined by an external wall 24 of the elongate member 14 and convergent and divergent portions 20,22 of the internal wall 18 of the body 12. Again, it will be appreciated that Figure 4(a) only illustrates half of the apparatus, with the half not illustrated being a mirror image about the longitudinal axis L of the illustrated portion.

The elongate member 14 of this fourth embodiment is adapted to include a second transport fluid passage 60 circumscribing the central working fluid passage 26. The transport and working fluid passages 60,26 are co-axial about the longitudinal axis L. With the second transport fluid passage 60 circumscribing the working fluid passage 26, the second transport fluid passage lies between the working fluid passage 26 and the first transport fluid passage 16. A number of first bores 62 allow fluid communication between the working fluid passage 26 and the second transport fluid passage 60. A number of second bores 64 allow fluid communication between the second transport fluid passage 60 and the first transport fluid passage 16.

In operation, working fluid is forced through the first bores 62 into the second transport fluid passage 60, where transport fluid shears the working fluid entering the passage perpendicular to the transport fluid flow. The resultant atomised fluid

then flows through the second bores 64 into the first transport fluid passage 16, whereupon it is sheared for a second time by a second flow of transport fluid. Providing two locations at which the working fluid is subjected to the shear forces of the transport fluid allows the apparatus to generate still smaller droplet sizes.

Figures 4(b) and 4(c) illustrate examples of communicating bores 70,72 which are not perpendicular to the flow of transport fluid through the transport fluid passage 16. The bore 70 of Figure 4(b) presents fluid into the transport fluid flow at an angle of less than 90 degrees such that the fluid flows against the flow of transport fluid. Such an arrangement increases the shear forces on the working fluid from the transport fluid. In Figure 4(c) the bore 72 is at an angle of over 90 degrees, so that the fluid flow is at an angle to the transport fluid flow, but is not perpendicular thereto. This arrangement reduces the amount of shear imparted on the working fluid by the transport fluid.

A fifth embodiment of the invention is illustrated in Figure 5. The elongate member 14 has a central working fluid passage 26 which ends in a cavity 28 remote from a working fluid inlet (not shown). A first transport fluid passage 16 is defined by an external wall 24 of the elongate member 14 and convergent and divergent portions 20,22 of the internal wall 18 of the body 12. In this

embodiment, the external wall 24 of the elongate member 14 tapers outwardly in the direction of the mixing chamber 19 and nozzle 32 until it reaches one or more second bores 64. Again, it will be appreciated that Figure 5 only illustrates half of the apparatus, with the half not illustrated being a mirror image about the longitudinal axis L of the illustrated portion.

The elongate member 14 of this fourth embodiment is adapted to include a second transport fluid passage 60 circumscribing the central working fluid passage 26. The transport and working fluid passages 60,26 are co-axial about the longitudinal axis L. With the second transport fluid passage 60 circumscribing the working fluid passage 26, the second transport fluid passage lies between the working fluid passage 26 and the first transport fluid passage 16. One or more first bores 62 allow fluid communication between the working fluid passage 26 and the second transport fluid passage 60. One or more of the second bores 64 allow fluid communication between the second transport fluid passage 60 and the first transport fluid passage 16.

A further difference between the fifth embodiment and the preceding fourth embodiment in particular is that a third transport fluid passage 80 is provided in the elongate member 14. The third transport fluid passage 80 may receive transport fluid from the same source as the first and second transport fluid passages 16,60, or else it may have its own

dedicated transport fluid source (not shown). The third transport fluid passage 80 has an outlet 82 which is on the downstream side of the first bore(s) 62. As a result, the outlets of the second and third transport fluid passages 60,80 are positioned either side of the first bores 62 and open into the second bores 64.

In operation, working fluid is forced through the first bores 62 from the working fluid passage 26, where transport fluid from the second and third transport fluid passages 60,80 shears the working fluid. The resultant atomised fluid then flows through the second bores 64 into the first transport fluid passage 16, whereupon it is sheared for a second time by a second flow of transport fluid. Providing two locations at which the working fluid is subjected to the shear forces of the transport fluid allows the apparatus to generate still smaller droplet sizes. By providing two sources of transport fluid from the second and third transport fluid passages 60,80 adjacent the first bore(s) 62, even smaller droplets of the working fluid can be obtained due to the effective twin shear action of the transport fluid on the working fluid prior to the atomised fluid entering the second bore(s) 64 and being further atomised.

Figures 6 and 7 show sixth and seventh embodiments of the apparatus, respectively, in which secondary shear actions take place in the manner of the fourth and fifth embodiments described above. In the sixth

embodiment shown in Figure 6, the elongate member 14 has a central working fluid passage 26 which ends in a cavity 28 remote from a working fluid inlet (not shown). A first transport fluid passage 16 is defined by an external wall 24 of the elongate member 14 and convergent and divergent portions 20,22 of the internal wall 18 of the body 12. The external wall 24 of the elongate member 14 runs substantially parallel to the transport fluid passage 26. One or more first bores 62 allow fluid communication between the working fluid passage 26 and the first transport fluid passage 16.

The key difference between the sixth embodiment and the fifth embodiment in particular is that a second transport fluid passage 90 is provided, but in this case the second transport fluid passage 90 is substantially perpendicular to the first transport fluid passage 16. The second transport fluid passage 90 may receive transport fluid from the same source as the first transport fluid passage 16, or else it may have its own dedicated transport fluid source (not shown). In this embodiment, the first transport fluid passage 16 has an outlet 17 in communication with the second transport fluid passage 90. A mixing chamber 19 is defined where the first and second transport fluid passages 16,90 meet one another. The second transport fluid passage 90 has a convergent-divergent internal geometry upstream of the first transport fluid passage outlet 17, thereby ensuring that the transport fluid passing through the passage 90 is

accelerated prior to meeting the atomised fluid exiting the first transport fluid passage 16.

In operation, working fluid is forced through the first bores 62 from the working fluid passage 26, where transport fluid from the first transport fluid passage 16 shears the working fluid. The resultant atomised fluid then flows through the outlet 17 into the second transport fluid passage 90, whereupon it is sheared for a second time by the second flow of transport fluid.

The seventh embodiment of the invention differs from the sixth embodiment in that the second transport fluid passage 100 is arranged such that the direction of the second transport fluid flow is generally opposite to the flow of transport fluid through the first transport fluid passage 16. As before, both the first and second transport fluid passages 16,100 have convergent-divergent internal geometry.

Working fluid exits the working fluid passage 26 via first bore(s) 62 in a flow direction perpendicular to the first transport fluid passage 16. Transport fluid accelerated through the passage 16 shears the working fluid exiting the bore(s) 62, creating an atomised fluid flow. The atomised fluid flow, flowing in the direction indicated by arrow D1, then meets the accelerated secondary transport fluid flow, illustrated by arrow D2, at a mixing chamber 19. The two fluid flows D1,D2 combine in the mixing

chamber 19 to further atomise the working fluid prior to the atomised working fluid exiting via outlet 104.

The purpose of the sixth and seventh embodiments is to shear the working fluid once and then carry the droplets into a further stream of transport fluid where the velocity of the droplets is reduced. This allows the production of uniform droplets by shearing with a first, preferably supersonic, stream of transport fluid and then reducing the velocity of the stream with the second transport fluid flow. These embodiments are for use in applications which require small droplet size but low projection velocities.

Each of the embodiments described here uses the generally perpendicular arrangement of the working fluid bores and transport fluid passages to obtain a crossflow of the transport and working fluids. This crossflow (where the two fluid flows meet at approximately 90 degrees to one another) ensures the penetrative atomisation of the working fluid as the transport fluid breaks up the working fluid. The natural Kelvin-Helmholtz/Rayleigh Taylor instabilites in the working fluid as it is forced into an ambient pressure environment also assist the atomisation of the working fluid.

Furthermore, by locating the elongate member 14 along the centre of the apparatus, the atomised working fluid exits the apparatus via an annular

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nozzle which circumscribes the elongate member. The elongate member effectively blocks the centre of the nozzle, which provides a further geometric mechanism to assist the atomisation of the working fluid. The blocking of the centre of the nozzle creates a low pressure recirculation zone adjacent the nozzle cone 15. As the high-speed atomised working fluid exits the annular nozzle it imparts further shear forces on the droplets in the recirculation zone, leading to a further atomisation of the working fluid.

In the fifth embodiment shown in Figure 5, the method of operation may be adapted by swapping the functions of the fluid passages 26,60,80. In other words, the passage 26 could supply the transport fluid, whilst the passages 60,80 supply the working fluid. In an alternative adaptation of the apparatus of the fifth embodiment, the apparatus could be adapted to feed gas bubbles through the first bores 62 as the working fluid passes through. This has the effect of breaking up the working fluid stream prior to atomisation and also increasing turbulence in the working fluid, both of which help improve the atomisation of the working fluid in the apparatus.

Further modifications and improvements may be incorporated without departing from the scope of the invention.

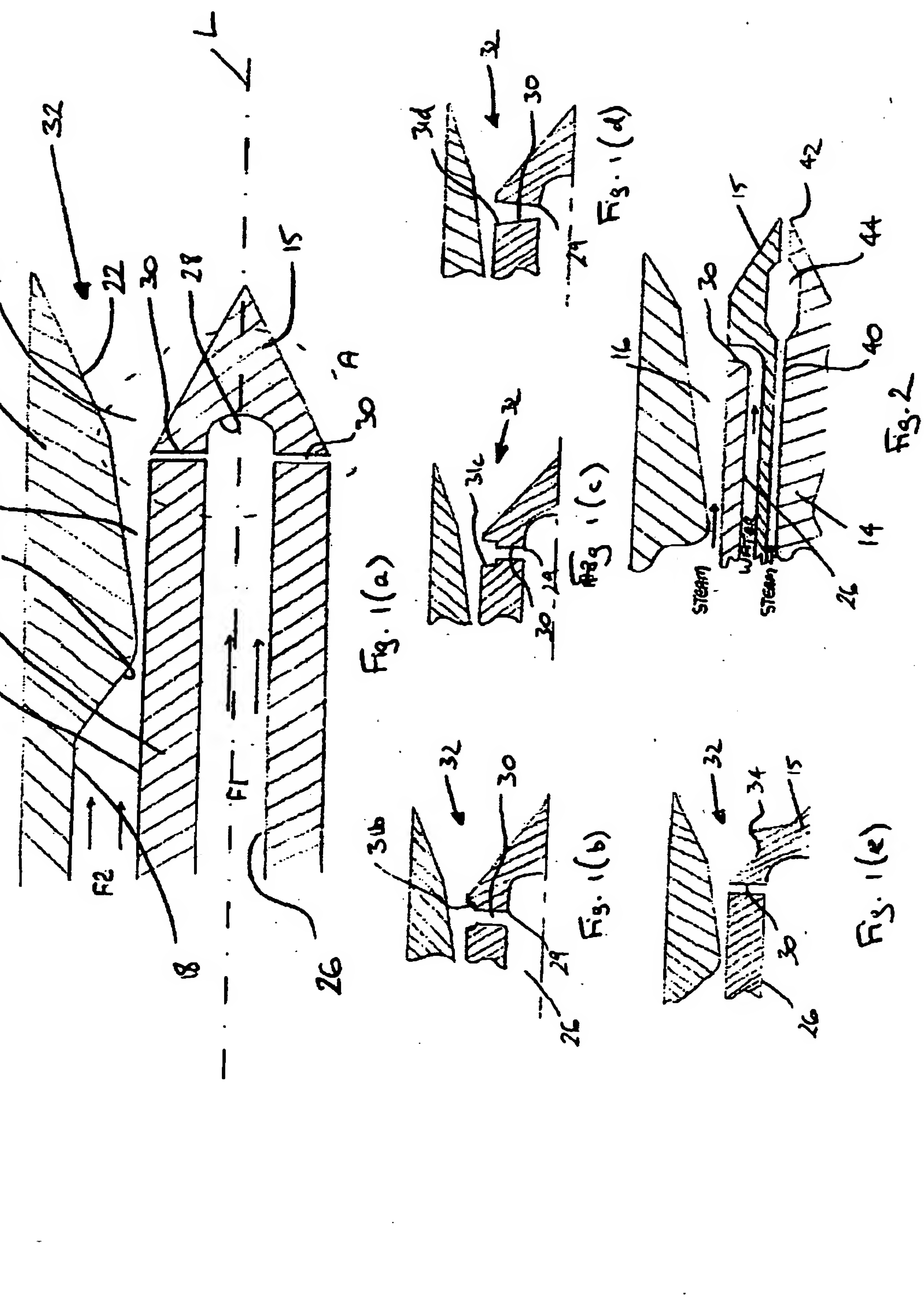
Fig. 1(a)
Fig. 1(b)
Fig. 1(c)
Fig. 1(d)
Fig. 1(e)
Fig. 2
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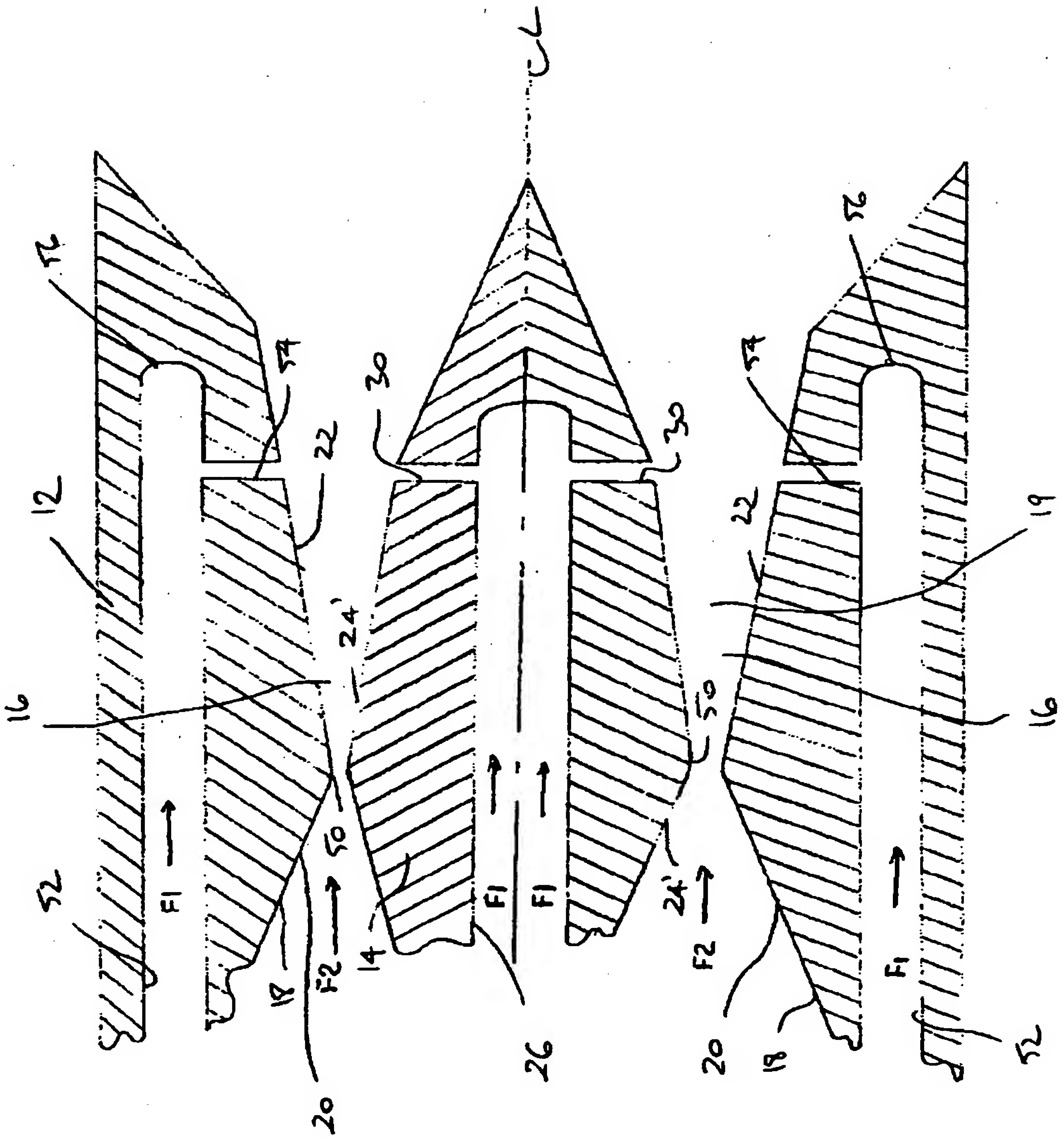

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Fig. 3

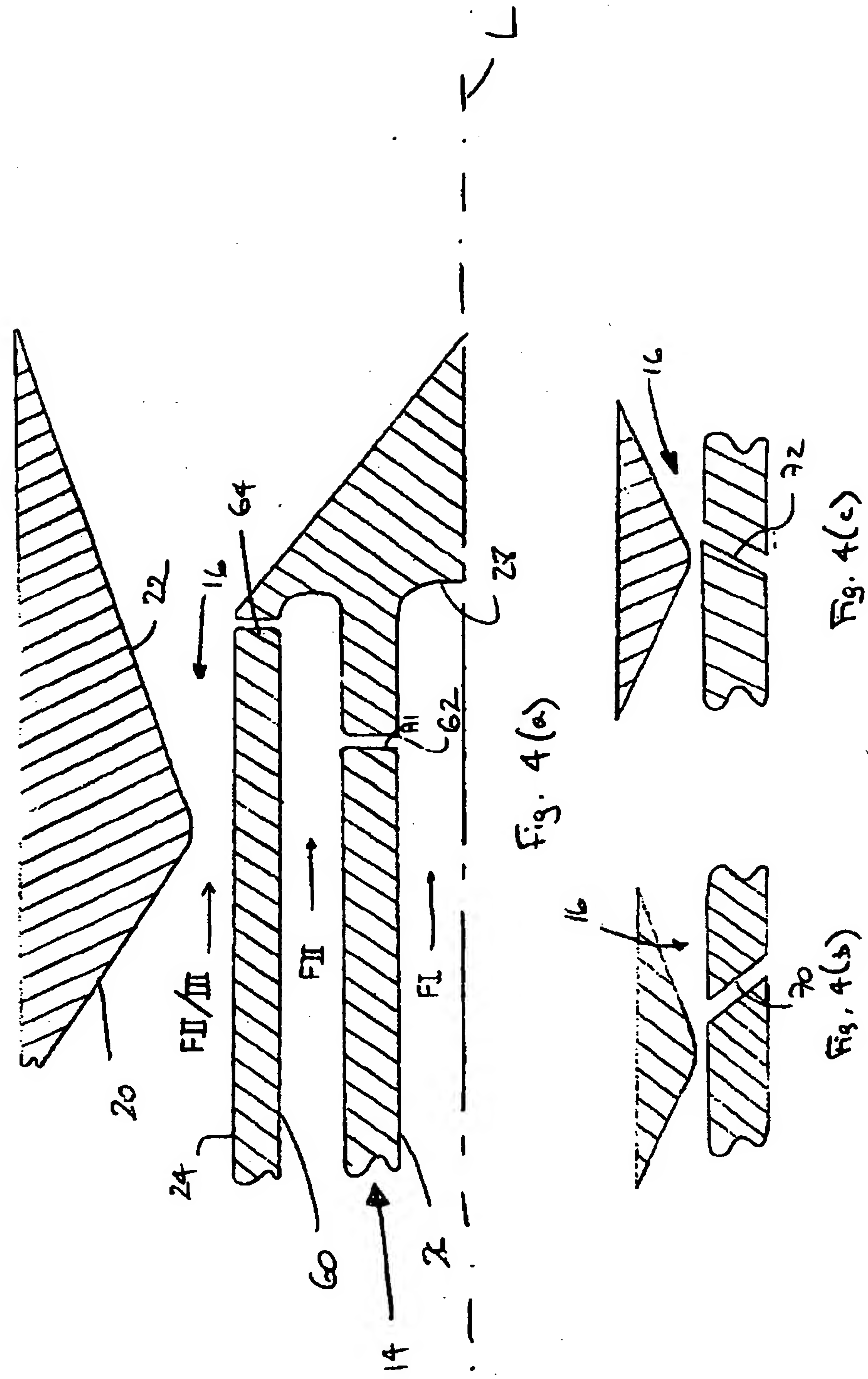

Fig. 4(a)

Fig. 4(b)

Fig. 4(c)

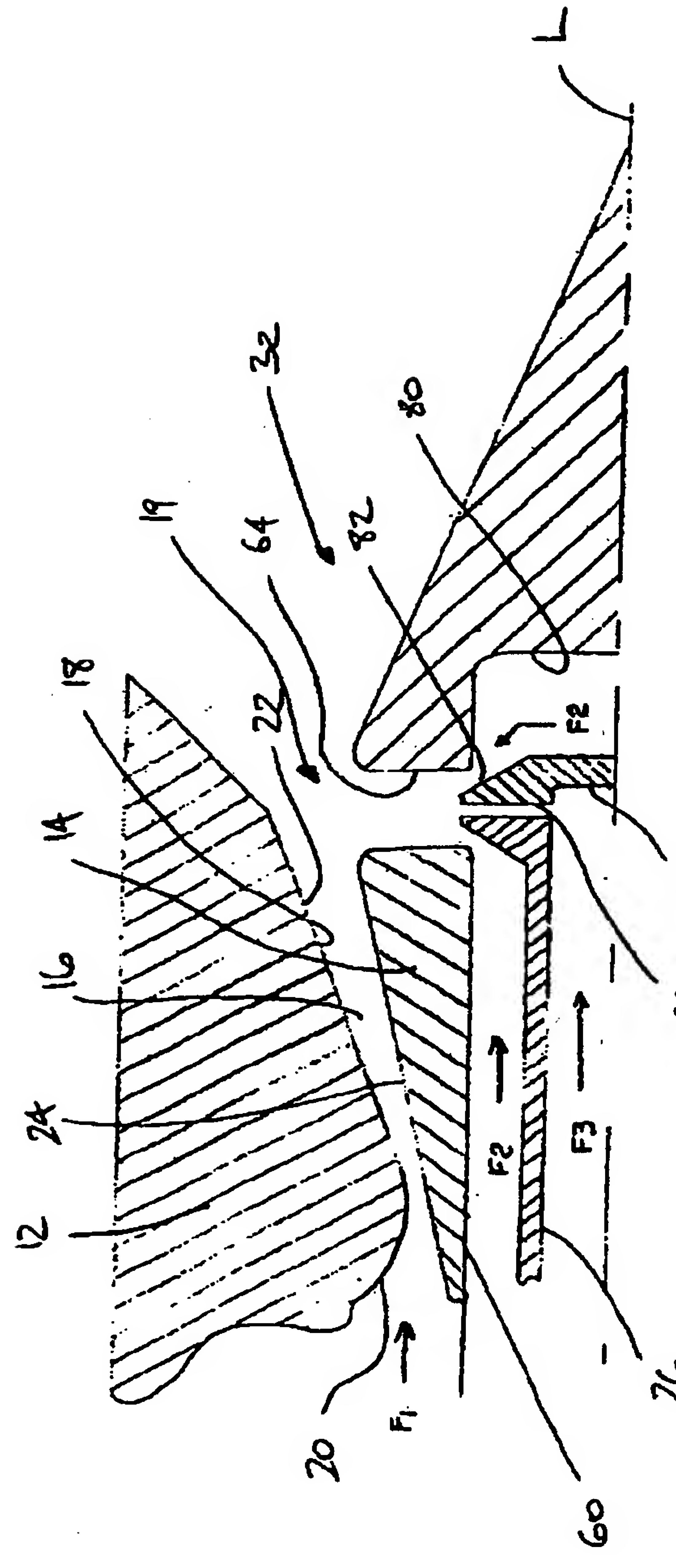

Fig. 5

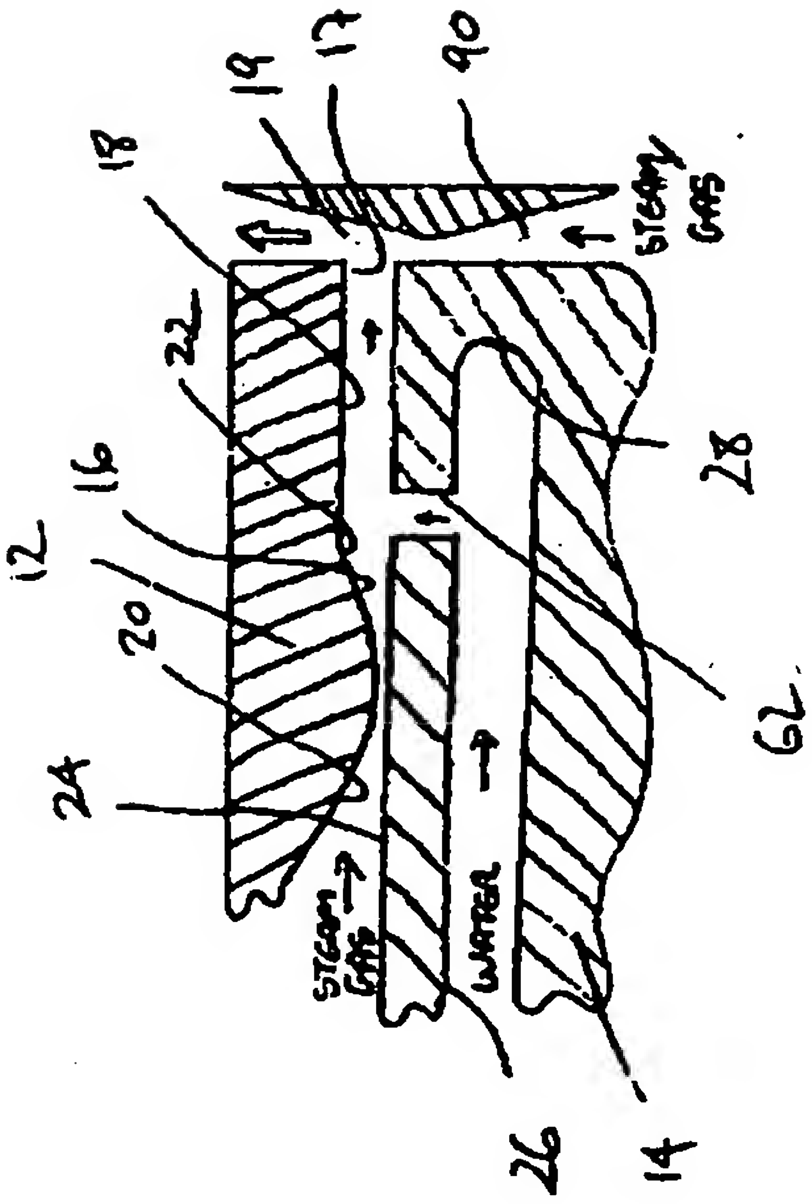

Fig. 6

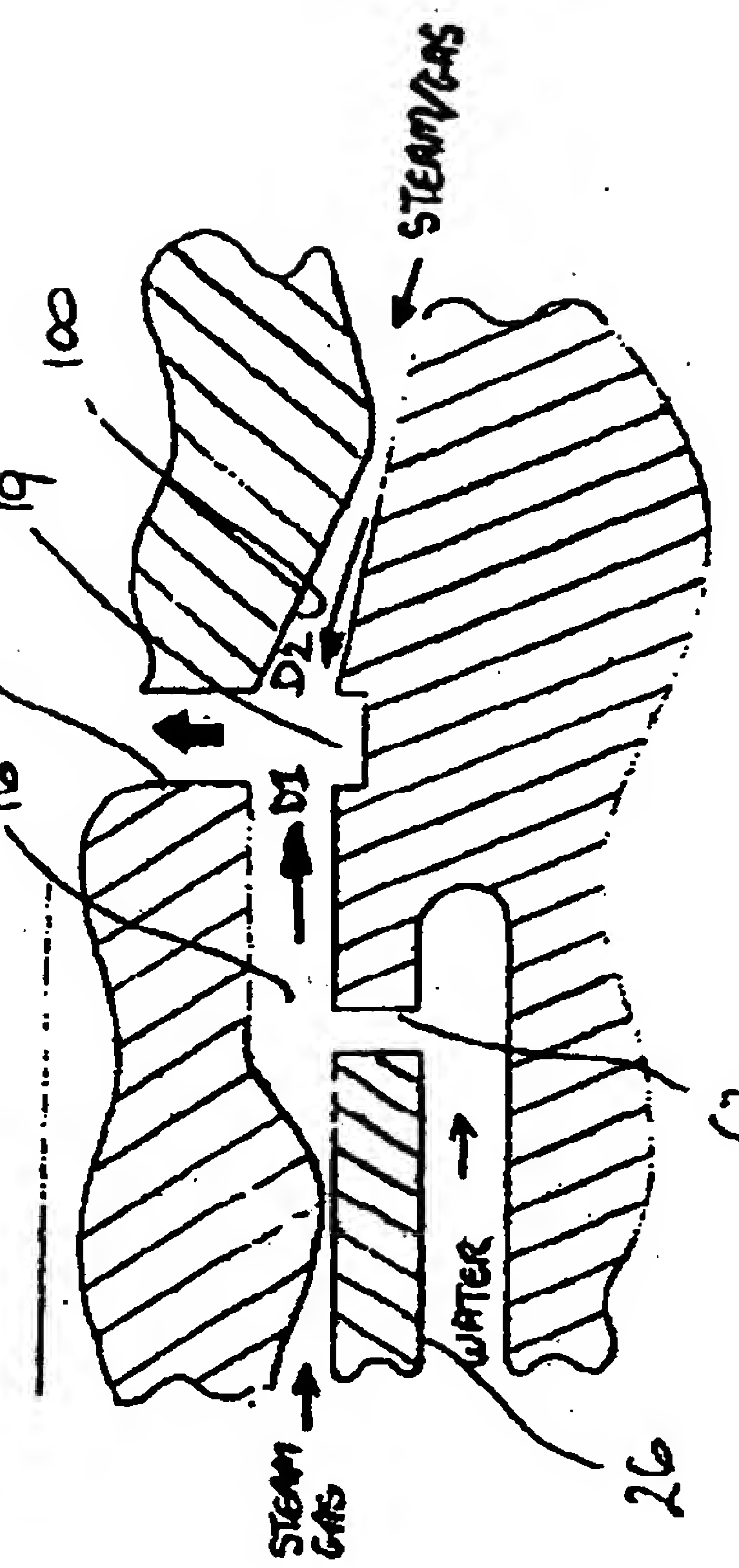

Fig. 7